Invasive terrestrial invertebrates in Victoria

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Abstract
A high number of exotic invertebrate species has been accidentally or deliberately introduced into Victoria since European settlement. The effects of these introductions on native flora and fauna have ranged from benign through to devastating, depending upon the species in question and on the context of their introduction. Exotic species are generally easier to identify, and in the case of potential future invasive species identified through such processes as pest risk analysis combined with vigilant quarantine inspection processes, it is possible to anticipate and identify potential paths of entry to prevent incursions in the first instance. However, subsequently dealing with exotic pests that have successfully established and native invertebrate species that have become pests is a more complex scenario. This paper discusses some of the significant exotic invertebrates to have established in Victoria and their impacts on the environment, either beneficial, benign or adverse. Impacts of exotic invertebrates on amenity plantings and forests are examined, as well as issues covering invasive native invertebrates establishing outside of either their normal host or geographic range. Broad actions to prevent or limit the spread of exotic and native invasive invertebrates are also discussed.
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Introduction

It is estimated that over 500 exotic species of insects and arachnids have become established in Australia since European settlement (Thomson *et al.* 1987). This figure included both accidental and deliberate introductions. No doubt, in the 20 years since this estimate was originally made, the number of exotic invertebrate species that has become established will have increased significantly.

This paper concerns 'invasive' invertebrates in Victoria. One definition of invasive invertebrates is 'a species that is not native to an ecosystem and whose introduction does or is likely to cause economic or environmental harm or harm to human health' (Chornesky *et al.* 2005). This definition links the concept of 'pest' to human interests.

The distinction between 'invasive' and 'pest' invertebrates is often blurred and ill-defined. Invasive species are often categorised as exotic species that have the ability to colonise rapidly and adapt to a particular environment, and in most cases, cause unwanted problems. Exotic species can be accidental or deliberate introductions but not all exotic species that are invasive become pests, and some have been deliberately introduced for primarily economic reasons such as the various biological control agents, earthworms and dung beetles. It is possible that a species introduced for economic purposes ultimately becomes a pest in its own right; cane toads, while not invertebrates, are an example of this.

The difficulty in defining invasive species is that not all invasive species are exotic. There are many examples of native species that naturally have large population boom and bust cycles and become pests, of which the Australian plague locust *Chortoicetes terminifera* (Walker) is a prime example. There are also native species that have been moved out of their natural range and become invasives, while some species have become invasives because of human mediated environmental change. Some exotic species have been deliberately introduced for beneficial reasons that may be perceived to have minimal environmental effects (biological control reasons) or there may be debate about these effects (e.g. European Honey Bees).

Hence the distinction between exotic, invasive and introduced species is rather arbitrary. This paper does not intend to undertake a comprehensive review of all invasive invertebrates in Victoria. More thorough treatments can be found in New (1994). We do not include economic pests of introduced agricultural plants, nor do we consider the occasional outbreaks of the native Australian plague locust. We will primarily deal with invertebrates that may have significant detrimental effects on the environment but whose effects can be mitigated by actions undertaken by people. This includes introduced exotics, introduced native species, and forest insects because of their potential to expand their ranges due to changes in land use such as the expansion of the eucalypt plantation estate, agroforestry and shelter belts.

Environmental and amenity aspects of invasive invertebrates

The following is a brief resume of the better known invertebrates that have been introduced into Victoria. Some exotic invertebrates, such as several species of spiders (Yen 1995), have been accidentally introduced, but the effects of these are not known. Except for the European Honey Bee *Apis mellifera* Linnaeus, the list does not include species such as dung beetles, earthworms, parasitic wasps and other biocontrol agents, deliberately introduced for beneficial economic and environmental reasons. Whether these groups have had any adverse effects on the native fauna is not known.

Exotics

Slugs and snails

There are over 60 native slug and snail species in southeastern Australia, with 10 introduced slug and 12 introduced snail species also present (Daniell 1994). The main observable environmental effects are grazing on native plant species by introduced slugs and snails. Introduced slugs appear to be prevalent on native grasslands (where there are no known native species of slugs) with the snail species *Theba pisana* (Müller) also recorded in very high numbers in some coastal dune areas (Smith 1967). Introduced snails are not limited to the terrestrial environment, with the exotic snail *Potamopyrgus antipodarum* (Gray) having colonised some lakes in Victoria (Schreiber *et al.* 1998).

Portuguese Millipedes

The Portuguese Millipede *Ommatoiulus moreletii* (Lucas) (Diplopoda: Julidae) was first recorded in Australia at Port Lincoln, South Australia, in 1953 (Baker 1985). It is now widespread in south-eastern Australia, including Victoria, where it can reach very high densities (Baker 1985). Portuguese Millipedes are attracted to light, and become a nuisance when they invade homes. They are particularly active in autumn when most problems occur. Portuguese Millipedes have invaded a range of habitats in Australia including *Eucalyptus* woodlands, grasslands, and domestic gardens. Baker (1985) reported that the highest densities occur in newly invaded areas, with populations subsequently declining as the invasion front moves on. Explanations for this decline include depletion of resources such as food, or the impact of natural enemies as native predators adapt to a new prey source. There is, as yet, no evidence that Portuguese Millipedes impact directly on native millipedes although there have been only limited studies of interactions (Baker 1985; Griffin and Bull 1995). Baker (1985) suggested Portuguese Millipedes may occupy a previously vacant detritivore niche in Australia, however, further research on the potential impacts of Portuguese millipedes in natural ecosystems is needed.

European Wasp Vespula germanica, *English Wasp* Vespula vulgaris

The European Wasp *Vespula germanica* (F.) (Hymenoptera: Vespidae) is native to Europe, North Africa and temperate Asia, but has subsequently spread to North America, New Zealand, South Africa, South America and Australia (Spradbery and Maywald 1992). The English Wasp *V. vulgaris* (L.) (Hymenoptera: Vespidae) is closely related to the European Wasp, and in Australia has established in Victoria and Tasmania (Lefoe and Ward 2001, Matthews *et al.* 2000). Within Victoria and Tasmania the range of English Wasps is believed to be more restricted than that of European Wasps, although mis-identification is probably common where their ranges overlap. European Wasps are generally considered the more serious pest in

Australia because of their abundance and widespread distribution.

The English Wasp was first discovered in Australia at Malvern, Victoria, in 1958 and while the initial infestation was destroyed, more were found in 1960. Despite attempted eradication, English Wasps continued to spread in an easterly direction, reaching the Dandenong Ranges in the early 1970s, and West Gippsland by the late 1970s. English Wasps are now also present in southeastern Tasmania, including Hobart, where they are thought to have arrived as recently as 1995 (Bashford 2001).

European Wasps possibly arrived in Australia from New Zealand, where they had initially been accidentally introduced and established (Spradbery and Maywald 1992). The first record of European Wasps in Australia was in 1954 at Sydney, where hibernating queens were discovered in a timber consignment from New Zealand (Chadwick and Nikitin 1969). The first nests were discovered in 1959 in Hobart, Tasmania, and later in New South Wales (1975), Western Australia and Victoria (1977) and South Australia (1978) (Spradbery and Maywald 1992). European Wasps have continued to spread across south and south-eastern Australia where they have quickly become widespread in Tasmania, Victoria and New South Wales (Spradbery and Maywald 1992). Crosland (1991) estimated unaided queen dispersal at only 730-815 metres per year. European Wasps, however, can spread more rapidly through accidental human transportation of hibernating queens (Crosland 1991). In South Australia, European Wasps remain a predominantly urban problem, although their numbers have increased steadily. While repeated introductions have occurred in Western Australia, with a large outbreak recorded in Perth in 1990, European Wasps are not yet considered to have successfully established in that state (Widmer and van Schagen 1995). In Queensland, reports of European Wasps occurred during 1988 and 1991, and the first nest was found in 1992 (Spradbery and Maywald 1992).

European and English Wasps impact on a number of different sectors in the community. In years of high abundance European and English Wasps can affect some agricultural industries such as Honey Bees and soft-fruit industries, especially grape growing and wine making operations. European Wasps can also cause serious injury, with hospitalisations due to stings increasing in Australia (Levick *et al.* 1997). European and English Wasps are particularly aggressive when their nest is threatened, and accidental disturbance of wasp nests poses a considerable threat to humans and other animals. In urban areas, the major concern is wasp stings, although disruption to outdoor activities and the cost of control add to the impact of wasps.

Most information on the deleterious impacts of wasps in natural ecosystems derives from studies conducted in New Zealand (Beggs and Wilson 1991, Harris and Oliver 1993, Beggs and Rees 1999). In natural ecosystems, wasps prey on native invertebrates, compete with native animals for food, disrupt natural ecosystem processes, and can pose a health risk to Parks staff and visitors. However there is very little detailed information on the impacts of wasps in Australian ecosystems. In Tasmania, European Wasps prey on the threatened Ptunarra Xenica *Oreixenica ptunarra* (M Driessen pers. comm. 2001). Bashford (2001) also reported that the number of calliphorid flies caught in Malaise traps at Warra, Tasmania, declined as the number of *Vespula* spp. increased. Continued studies at the site may determine whether introduced *Vespula* wasps have any long term impact on populations of calliphorid flies and other prey species.

The European Honey Bee, Apis mellifera

The European Honey Bee, *Apis mellifera*, has been in Australia for over 100 years. It has been an important part of the economy in the provision of honey, but there has been considerable debate about whether it has been detrimental to native bees and other insects, native birds and native plants. Paton (1996) concluded that it was difficult to generalise about the effects of *A. mellifera*, and in a special issue of *The Victorian Naturalist*, New (1997), Schwarz and Hurst (1997), Manning (1997), and Paton (1997) presented different perspectives on the issue. Paini and Roberts (2005) provided some preliminary evidence on *A. mellifera* affecting native bees, but Paini (2004) stated that possibly any adverse effects are historical. In fact, Yates *et al.* (2005) give one example in an urban park where feral Honey Bees may be the major pollinator of some native plant species. To complicate the matter further, there could be potential flow-on effects if the Honey Bee Mite *Varroa destructor* (Anderson & Trueman) gets into Australia (Cunningham *et al.* 2002).

Tramp ants

Environmental conditions in Australia have resulted in the evolution of a very rich and diverse ant fauna that undertakes a range of important ecological functions (Andersen 1983). A significant threat therefore to the Australian environment is the establishment of exotic ant species. Several species have been identified as invasive and have colonised different parts of the world primarily by hitch-hiking on freight transport. These ants, collectively named tramp ants, originate mainly in Central and South America, Africa or South Asia (McGlynn 1999), and have colonised both urban and natural habitats. Australia has been colonised by eleven tramp ant species: the ghost ant *Tapinoma melanocephalum* (Fabricius), the white-footed ant *Technomyrmex albipes* (F. Smith), the red imported Fire Ant *Solenopsis invicta* (Buren), the Crazy Ant *Paratrechina longicornis* (Latreille), the Yellow Crazy Ant *Anoplolepis gracilipes* (Fr. Smith), the African Big-headed Ant *Pheidole megacephala* (Fabricius), the Argentine Ant *Linepithema humile* (Mayr), the Singapore Ant *Monomorium destructor* (Jerdon), the Pharoah Ant *Monomorium pharaonis* (Linnaeus), the Tropical Fire Ant *Solenopsis geminata* (Fabricius) and the Little Fire Ant *Wasmannia auropunctata* (Roger) (Commonwealth of Australia 2006). Whereas specimens of the Pharaoh Ant were collected in St Kilda in 1938, and the Singapore Ant in Camberwell (1939) and Myrtleford (1940), these two species are primarily tropical and these records probably reflect more transient than established populations (John Wainer, pers. comm. 2006). The African Big-headed Ant was found in Melbourne by Clark (1941) and more recently by Wainer (pers. comm. 2006). The red imported Fire Ant entered Victoria in 2001 via potted palm trees originating from Queensland, where it is under eradication, and in soil on a shipping container from the USA. Both these Victorian incursions were subsequently eradicated (John Wainer, pers. comm. 2006).

The major tramp ant species in Victoria is the Argentine Ant. This species was first found in Balwyn in 1939 (Clark 1941), and it is thought to have spread from this initial colony to colonise Tasmania, New South Wales, the ACT and Western Australia. It is primarily a pest of urban environments where it can nest in suitable cavities outside homes from which they can establish large foraging trails into houses to seek food and water. Colonies can range in size from a dozen to many thousands and they can establish satellite nests that are highly mobile. However, their pest status spreads beyond the urban environment and they have an impact in orchards by protecting honeydew producing insects such as aphids and scales against their natural predators and parasitoids. There are reports of Argentine Ants reducing the abundances of native ants in California (Holway 1998), Hawaii (Cole *et al.* 1992), South Africa (Bond and Slingsby 1984) and Japan (Touyama *et al.* 2003). Recently, Rowles and O'Dowd (2007) demonstrated that the Argentine Ant displaced native ant species from baits in coastal scrub vegetation on the Mornington Peninsula. This displacement has the potential to alter plant community composition because some of the displaced native ant species (species of *Pheidole* and *Rhytidoponera*) are important dispersal agents and predators of seeds.

Elm Bark Beetle, Elm Leafhopper, Elm Leaf Beetle

In Australia the exotic elm tree *Ulmus* spp. has been widely planted in urban landscapes, especially in Victoria. The largely pest-free status of elms in Australia changed in 1974 when the smaller European Elm Bark Beetle, *Scolytus multistriatus* (Marsham) (Coleoptera: Curculionidae), was discovered in Melbourne. While its mode of entry into Australia has not been precisely determined, it possibly occurred through the

Port of Melbourne, using dunnage as its vector. Later surveys subsequently found the smaller European Elm Bark Beetle to be well established in Victoria (Neumann and Minko 1985) and it has since spread into New South Wales, the Australian Capital Territory and South Australia (Neumann 1987). The smaller European Elm Bark Beetle, while widespread, is usually considered a minor pest in the absence of the Dutch elm disease (DED) pathogen. However, as a known vector of the causal agents of DED, *Ophiostoma ulmi* (Buisman) and *O. novo-ulmi* Brazier, the beetle has the potential to rapidly spread these pathogens should they be introduced into Australia.

In 1986 the Elm Leafhopper, *Ribautiana ulmi* Linnaeus (Hemiptera: Cicadellidae) was observed on elms around Melbourne although its mode of entry is not known. This species of leafhopper causes cosmetic damage or 'speckling' of leaves by damaging leaf mesophyll cells. There is very little known of its long-term effects on tree health and it is usually considered a minor pest (Missen *et al.* 1991).

The Elm Leaf Beetle, *Pyrrhalta luteola* Müller (Coleoptera: Chrysomelidae), a serious pest of European elms, was first discovered on the Mornington Peninsula, Victoria, in 1989 (Kwong and Field 1994). While its mode of introduction is again unknown, it was well established before its initial discovery. The elm leaf beetle is now defoliating elms in metropolitan Melbourne and much of regional Victoria (Lefoe 1999). Where infestations occur, control measures are required to be implemented immediately to prevent serious defoliation damage occurring. If not adequately controlled, Elm Leaf Beetle is likely to shorten the lives of elms in Australia and can make them more prone to attack from the smaller European Elm Bark Beetle.

Native species

Moreton Bay Fig psyllid

The Moreton Bay Fig *Ficus macrophylla* is native to New South Wales and Queensland, being widespread in coastal scrub and coastal rainforest (Floyd 1989). It is a large tree, up to 50 metres high, and has been planted widely in parks and gardens in Victoria. A native psyllid *Mycopsylla fici* (Tryon) (Hemiptera: Homotomidae) causes significant damage to Moreton Bay Figs in Victoria (Honan and McArthur 1998). Feeding by immature psyllids causes localised leaf necrosis and early leaf fall. Fallen leaves containing sticky lerps are also a nuisance to pedestrians and potentially hazardous when they stick to shoes on wet paths. For these reasons chemical control of psyllids is sometimes necessary, although the size of the trees, and the protection afforded by the sticky lerps has made control difficult. Recent studies (Honan and McArthur 1998; Lefoe 2005) have provided useful information to enable tree managers in Victoria to monitor psyllid populations and determine whether control is necessary. A native parasitoid *Psyllaephagus* sp. (Hymenoptera: Encyrtidae) is present in Melbourne (Honan and McArthur 1998), further highlighting the need to conduct chemical applications prudently. Although both *M. fici* and *Psyllaephagus* sp. are common in central Melbourne, their statewide distribution is not known.

Forestry aspect of invasive invertebrates

Exotic invertebrates

Quarantine provides the first line of defence against the unwanted introduction into Australia of forestry-related insect pests, and their subsequent establishment in the plantation estate (Lawrence 1963; Department of Primary Industries and Energy 1996). This involves the careful inspection by trained observers of all wood products and related material capable as acting as a vector for forest insect pests, and the treatment or immediate destruction of any pests once found. Regular reviews are also conducted to allow for new products and pathways of entry that continually develop (Senate Standing Committee on Natural Resources 1979). Despite continual enforcement of strict quarantine measures at Australian ports, at least 46 species of exotic forestry-related insect pests have breeched quarantine barriers and established in Australia (Table 1).

An 'established forest insect pest' is defined as an exotic insect that has passed through a complete generation or lifecycle on or within a native or exotic tree

Table 1. Some exotic forest/forest product insect pests, or related organisms, known to have established in Australia (Department of Primary Industries and Energy 1996).

Order/family	Genus/species	Comments
Acarina (mites, ticks)		
Tetranychidae	*Oligonychus ununguis* (Jacobi) Spruce spider mite	Damage to foliage of *Pinus* spp. in Queensland (Wylie 1978)
Isoptera (termites, 'white ants')		
Kalotermitidae	*Cryptotermes brevis* (Walker) West Indian drywood termite	Damage to seasoned exotic and native softwoods and low-density hardwoods (Gay 1967) established in Queensland during 1930s and detected in NSW in 1946 (Heather 1971; Eldridge and Simpson 1987)
	C. cynocephalus Light	Damage to seasoned timber, probably introduced during 19th century (Wylie, DPI Qld, pers.comm.)
	C. domesticus (Haviland)	Damage to seasoned timbers, introduced in early 1950s (Yule and Watson 1976; Miller and Paton 1983)
	C. dudleyi Banks	Damage to seasoned timbers introduced during the 19th century (Wylie, DPI Qld, pers.comm.,)
Hemiptera (bugs)		
Adelgidae	*Pineus pini* (Macquart) Pine adelgid	Damage to foliage of *Pinus* spp. on marginal sites (Tanton and Alder 1977)
Aphidae	*Elatobium abietinum* (Walker) Spruce aphid	Damage to foliage of *Picea* spp. (Naumann 1993)
	Essigella californica (Essig) Monterey Pine aphid	Damage to foliage of *Pinus* spp. (Collett et al. 2000)
	Euceraphis betulae (Koch) European birch aphid	Damage to foliage of *Betula* spp. (Naumann 1993)
	Myzocallis castanicola Baker Oak aphid	Damage to foliage of *Quercus* spp. (Naumann 1993)
	Pemphigus bursarius (Linnaeus) Poplar gall aphid	Damage to foliage of *Populus* spp. (Naumann 1993)
Cicadellidae	*Ribautiana ulmi* (Linnaeus) Elm Leafhopper	Damage to foliage of *Ulmus* spp. (Neumann 1991)
Coleoptera (beetles)		
Anobiidae	*Anobium punctatum* (De Geer) Furniture beetle	Damage to seasoned softwoods (French 1968, 1970; CSIRO 1939)
	Ernobius mollis (Linnaeus) Pine bark anobiid	Damage to bark of softwood (Brimblecombe 1957)
Bostrichidae	*Dinoderus minutus* (Fabricius) Bamboo borer	Wylie and Yule (1977)
	Lyctus brunneus (Stephens) Powderpost beetle	Serious damage to seasoned sapwood of many eucalypts and brushwoods (Rosel 1969; Wylie and Yule 1977)
	L. discedens Blackburn Small powderpost beetle	As above
	Minthea rugicollis (Walker) Hairy powderpost beetle	Damage to seasoned sapwood (Wylie and Yule 1977)

Table 1 cont.

Order/family	Genus/species	Comments
Coleoptera (beetles)		
Bostrichidae	*Rhyzopertha dominica* (Fabricius) Lesser grain borer	Wylie and Yule (1977)
	Xylopsocus gibbicollis (Macleay) Common auger beetle	Wylie and Peters (1987)
	Xylothrips religiosus (Boisduval) Northern auger beetle	Wylie and Yule (1977)
Cerambycidae	*Aridaeus thoracicus* (Donovan) Tiger longicorn	Wylie and Peters (1987)
	Hylotrupes bajulus (Linnaeus) European house borer	Damage to seasoned softwood timber (Howick 1966)
Chrysomelidae	*Pyrrhalta luteola* (Müller) Elm Leaf Beetle	Damage to foliage of *Ulmus* spp. Established in Victoria in or before 1989 (Neumann 1991; Kwong and Field 1994)
Curculionidae		
Platypodinae	*Crossotarsus mniszechi* Chapuis	Ambrosia beetle; Wylie and Yule (1977)
	Diapus pusillimus Chapuis Walnut pinhole borer	As above
	D. quinquespinatus Chapuis	As above
	Platypus parallelus (Fabricius) Common ambrosia beetle	As above
Scolytinae[1]	*Eccoptopterus sexspinosus* (Motschulsky)	Wylie and Yule (1977)
	Hylastes ater (Paykull) Black pine bark beetle	Usually in inner bark of dead pine material, occasionally kills young seedlings on second rotation sites (Minko 1958; Neumann 1987)
	Hylurgus ligniperda (Fabricius) Goldenhaired bark beetle	As above
	Ips grandicollis (Eichhoff) Fivespined bark beetle	Mostly 'secondary', but occasionally a 'primary' tree killer of *Pinus* spp. Established since 1942 (Morgan 1967, Rimes 1959, Neumann and Morey 1984)
	Phloeosinus cupressi Hopkins Cypress bark beetle	Neumann (1987)
	Scolytus multistriatus (Marsham) Elm Bark Beetle	Established since 1974 in Victoria; carrier of Dutch Elm Disease (Rosel and French 1975; Neumann and Minko 1985)
	Xyleborus ferrugineus (Fabricius)	Established in Queensland before 1971 (J.King, DPI Qld, pers.comm.); has attacked green logs of Bunya pine in Queensland; also logs from fire-killed Pinus spp. (Wylie *et al.* 1996)
	X. fornucatus Eichhoff	Booth *et al.* (1990)
	X. indicus Eichhoff	Wylie and Yule (1977)

Table 1 cont.

Order/family	Genus/species	Comments
Coleoptera (beetles)		
	X. perforans (Wollaston) Island pinhole borer	As above
	X. saxeseni (Ratzeburg) Fruit-tree pinhole borer	Neumann and Minko (1985)
	X. similis Ferrari	Booth *et al.* (1990)
	X. solidus Eichhoff Thickset scolytid borer	Naumann (1993)
	X. torquatus Eichhoff	Wylie and Yule (1977)
Lepidoptera (butterflies, moths)		
Gracillariidae	*Phyllonorycter messaniella* (Zeller) Oak leafminer	Damage to foliage of *Quercus* spp. (Naumann 1993)
Hymenoptera (wasps ants bees, sawflies)		
Siricidae	*Sirex noctilio* Fabricius Sirex wasp	The most destructive tree-killing pest in plantations of *Pinus* spp. Established in Tasmania in 1950s and in Victoria in 1962 (Gilbert and Miller 1952; Irvine 1962; Neumann and Minko 1981)
Vespidae	*Vespula germanica* (Fabricius) European wasp	Important pest in operational and recreation forestry (Dept.Agric.Vic. 1983; Crosland 1991)
	V. vulgaris (Linnaeus) English wasp	Detected in Victoria in 1958; important pest in operational and recreation forestry (Dept.Agric.Vic. 1983)

[1] Sub-family Scolytinae is reported to contain 92 established species in Australia, of which 26 are considered exotic (Brimblecombe 1953).

species or originally uninfested imported or locally produced wood product. life-cycles however, can vary substantially between insect pest species resulting sometimes in variations of times when the insect pest entered Australia and when it was first detected. For example, the Asian Gypsy Moth *Lymantria dispar* (Linnaeus), a foliage feeder with a one year life-cycle is potentially more detectable in its early establishment phase than the European House Borer (*Hylotrupes bajulus* (Linnaeus)), a less visually apparent wood boring insect that has a life-cycle of between one and twenty years.

The frequency of exotic insect pest interceptions is generally linked to two factors, namely the countries/regions with which we conduct the major part of our trade and the pathway (mode of entry) by which the exotic pest gains entry. Studies by Wylie and Peters (1987) found that the majority of intercepted wood-boring insect taxa originated in Asia (46.1%) with the next largest group originating from the Australasia/Pacific region (30.4%), with Asia especially being our most significant trading region. However, care should be taken in the interpretation of such trends. For example, Australia conducts significant trade with North America and yet interceptions account for only 6.9% of total interceptions, indicative of potentially more strict quarantine procedures prior to goods being exported and the types of goods exported.

In examining the modes of entry by which insect pests enter Australia, studies have found that sawn timber and wooden crates account for 45% and 30% respectively of all interceptions (Wylie and Peters 1987). Using such data is useful in directing sometimes scarce resources to monitor the most likely entry pathways for future insect pest incursions into Australia.

Impacts of forest insect pests
In terms of forestry, most invasive exotic invertebrates have impacted on exotic plantation species such as *Pinus radiata* D.Don although a few native insect species such as *Lichenaula* spp. (a defoliating moth species) have adapted to exotic tree species such as *P. radiata* and, on occasion, cause varying degrees of damage. One of the most significant insect pest species of *P. radiata* is Sirex Wood Wasp *Sirex noctilio* Fabricius, first recorded in Victoria in 1961 where it caused significant tree mortality before the introduction of various biocontrol and silvicultural control methods in the 1970s and 1980s. Sirex, through the introduction of phytotoxins, not only kills trees but also renders the timber subsequently useless for construction or pulping purposes. In the mid-1970s a severe outbreak of Sirex caused extensive tree mortality in the Delatite area of north-east Victoria (Neumann *et al.* 1987), while lesser outbreaks have been recorded in south-west Victoria near Rennick in the mid-1980s and around Shelley in north-east Victoria in the late 1990s.

A recently introduced aphid species the Monterey Pine aphid (*Essigella californica* (Essig)) first observed in north-east Victoria in the late 1990s has established throughout the pine estate where it has caused significant defoliation damage over a wide area. Symptoms of damage include mottled chlorosis of the older needles followed by premature needle shed with defoliation most predominate in the upper crown between March and July (Collett *et al.* 2000). However, defoliation of the lower crown can also be associated with very severe levels of aphid attack (Collett *et al.* 2000). Defoliation is predominantly observed in pine stands greater than 15 yrs of age. However, it has also been observed occurring in stands of all age classes (Collett *et al.* 2000). Such defoliation has been shown to result in substantial reductions in incremental growth and associated declines in timber yields (May 2004). Initial surveillance data have shown defoliation to be most pronounced in north-east Victoria and to a lesser extent in the Ballarat region, coinciding with regions where mean autumn daily temperatures of approximately 22° C predominate.

The Fivespined Bark Beetle *Ips grandicollis* (Eichhoff) and to a lesser extent the Golden-haired Bark Beetle *Hylurgus ligniperda* (Fabricius) and Black Pine Bark Beetle *Hylastes ater* (Paykull) generally attack young, newly established seedlings in plantations where sometimes widespread mortality is caused through lethal feeding attacks in the outer cambium layers of trees (Neumann and Morey 1984; Department of Conservation, Forests and Lands 1988). Attack is most predominant in summer months when the higher temperatures allow rapid increases in beetle populations in freshly felled green slash on logged sites, before damaging feeding and breeding attacks on adjacent young trees and seedlings. Damage by *Ips* is also caused to freshly felled logs stored on logging landings where feeding attacks allow the introduction of blue stain fungus *Diplodia pinea* (Desm.) into timber, rendering it subsequently useless for pulp paper production. Widespread *Ips* attacks on seedlings and young four-year-old Radiata pine trees have been documented in south west Victoria in the early 1980s with lesser attacks occurring around Myrtleford and Bright (Department of Conservation, Forests and Lands 1988).

While these examples are by no means comprehensive, they serve to show the variety of age classes attacked, the range of damage (i.e. defoliation and borer damage) caused and the spread of seasons and locations in which damage is caused. Some pests have an already long history within Victoria (i.e. Sirex), with comprehensive information available on their 'attack profiles'. However, some of the more recent introductions such as the Monterey Pine aphid require longer term research coupled with ongoing surveillance to develop pest profiles so as to assist in making more informed longer term management decisions.

Invasive native pest invertebrates
In terms of invasive native invertebrates within a forestry setting in Victoria, this

concept requires a more detailed definition of what situations we consider a native insect to be termed a 'pest' species. In native forests it is difficult to define adequately outbreaks of native invertebrate species such as the Red Gum psyllid *Cardiaspina retator* (Taylor), Gumleaf Skeletoniser *Uraba lugens* Walker and Spurlegged Phasmatid *Didymuria violescens* (Leach) as 'pest outbreaks'. Such 'outbreaks' are well documented in the literature throughout Victoria in the past 50-60 years (Neumann and Marks 1976; 1990; Neumann 1978; Collett 2001; Harris 1972; Elliott *et al.*1998) and it could be suggested that such outbreaks are cyclical and form part of the normal 'ebb and flow' of invertebrate activity within native forests. Only when these 'outbreaks' impact on economic activities such as harvesting and logging or on the aesthetics of forest areas with parks and reserves could we possibly consider them 'pest outbreaks' in the traditional sense. When examining the 'invasive' aspects of such outbreaks, there is no substantial documented evidence that any of these 'pest species' generally move beyond their expected geographic range when in outbreak mode to native forest areas outside this range. Only when these insect species are found within native plantations may it be reasonable therefore to treat them as 'invasive pest' species. An example of this scenario is *U. lugens* in north central Victoria, which has caused occasional defoliation to *E. camaldulensis* (Dehnh.) plantations (Collett pers. comm. 2006), with the original populations having originated within native red gum forests in the region. In these situations, the possibility of parallels being made with exotic insect incursions in exotic softwood plantations could be made, although the potential to control such outbreaks, especially using methods such as biological control, would be substantially diminished.

Of concern, however, is the potential for eucalypt plantations using tree species planted well out of their native range to 'draw in' native insect pest species, which in turn may divert either on to local native plant species or alternative native plantation species. The situation may also arise whereby the spread of these 'invasive' native pests may not be accompanied by their range of native biocontrol agents. Examples of this scenario include *E. grandis* (Hill) plantings at Mildura, which have drawn in populations of Autumn gum moth *Mnesampela privata* (Guenee) into the region (Bashford 1998).

Future threats posed by exotic pest incursions

The list of exotic insect pest species likely to cause considerable damage to the plantation industry in Victoria is potentially enormous. Until an exotic pest species has entered and established, there is no certain way to determine the exact threat it poses to both native and exotic plantation tree species. However, in order to plan for the eventuality of such exotic insect pest incursions occurring, rigorous interrogation of available information is conducted to determine the country of origin of potentially dangerous insect pests, including such information as their host tree species range, life-cycle and optimal environmental conditions for development both in their country of origin and Australia. This information is incorporated into pest profiles known as Pest Risk Assessments (PRAs) which can be specific to individual pest species or generically written to cover a range of insects posing a similar risk. A PRA includes all known available information on a pest species as well as contingency plans for dealing with an incursion and potential outbreak of the pest in Australia. The lists of potential pest species and associated PRAs varies constantly as new information is gathered, examined and updates provided accordingly.

While many insect pest species pose a considerable threat to plantations, a small subset has been selected as species with the greatest potential to establish and cause significant economic and environmental damage. This list is shown in Table 2 and was compiled by the Australian Quarantine and Inspection Service (AQIS) in consultation with state forestry authorities (Commonwealth of Australia 2001). Of the species listed, the majority are borer species with the potential to enter Australia cryptically within timber products, and consequently are sometimes difficult to assess fully and subsequently treat. Other pests such as the potentially highly

Table 2. Exotic forest/timber insect pest species yet to establish in Australia posing a potentially considerable threat to forest and amenity trees and timber in service (Commonwealth of Australia 2001).

Genus/species	Origin	Comments/Potential Impact
Isoptera (termites)		
Coptotermes formosanus Shiraki	China, Taiwan, Japan, Sri Lanka South Africa, USA (Hawaii)	Can severely damage timber in buildings. Very destructive.
Incisitermes minor (Hagen)	USA, Mexico, Canada	A serious pest of timber in service.
Coleoptera (beetles)		
Anoplophora glabripennis (Motschulsky)	Sth China, Korea, Japan USA (parts of)	Serious hardwood pest (eucalypts, pears, apples)
Arhopalus ferus (Fabricius)	UK, Europe, Russia, New Zealand	Pest of windthrown and fire damaged trees
Stromatium barbatum (Fabricius)	India, Sri Lanka, Burma, Mauritius Madagascar, Pakistan, Nepal	Pest of seasoned timber with large host range
Hylotrupes bajulus (Linnaeus)	Europe, Middle East, Africa, Asia, Sth America, USA, China	Highly destructive pest of seasoned softwood
Vanapa oberthuri (Pouillaude)	Papua New Guinea, Indonesia	Serious impact on native *Araucaria* species
Ips typographus (Linnaeus)	Europe, China, Japan, Korea Russia	Serious pest of spruce species
Dendroctonus ponderosae Hopkins	Canada, USA	Attack leads to introduction of wood decaying fungi
Heterobostrychus aequalis (Waterhouse)	Europe, India, Asia, Middle East, South Africa	Attacks exposed wood in houses, furniture and panelling.
Lepidoptera (moths, butterflies)		
Lymantria dispar (Linnaeus)	China, Eastern Russia, Korea, Japan, USA	Highly destructive defoliator of over 600 tree species
L. monachal (Linnaeus)	As above	Defoliator of numerous tree species (elms, oaks, conifers)
Orgyia thyellina Butler	China, Korea, Eastern Russia, Japan, Taiwan	Serious pest of exotic ornamental tree species
Hymenoptera (bees, wasps, ants)		
Camponotus pennsylvanicus (De Geer)	USA, Canada	Pest of seasoned timber in service
Urocerus gigas (Linnaeus)	Asia, Europe, Chile, USA, Canada, Russia	Can kill stressed trees (pines and other conifer species)

destructive Asian Gypsy Moth (Matsuki *et al.* 2000), while more visible as their egg masses are laid on object surfaces, can lay these egg masses on a variety of material (i.e. timber, metal, plastics, etc) and consequently, require more detailed examination in order to locate and treat.

The future: possible effects of invasive invertebrates on ecosystem function and solutions

The question that arises is whether in the long term some of the invasive species become naturalised or 'integrated' into the Australian fauna or whether they have a significant adverse effect on the structure and functioning of Australian ecosystems. The Australian environment is unique in that a significant proportion of its invertebrate fauna is dependent upon the dominant *Eucalyptus* and *Acacia* flora (Majer *et al.* 1997). Many tens of thousands of plant-feeding insect species have co-evolved with their *Eucalyptus* or *Acacia* host plants, and there is a complex, but poorly understood, relationship that involves varying degrees of host plant specificity (from monophagous – feeding on only one host plant species, through to polyphagous), and the ability to utilise different host plant species in different locations (Fox and Morrow 1981). It is possible that colonisation of different host plant species by polyphagous species (either native or exotic) may result in the reduction of insect diversity associated with *Eucalyptus* and *Acacia*. The spread of some of these polyphagous species through the Australian environment may be aided by tree planting, agroforestry, and the spread of weedy native species. An example of the latter may be the spread of the weedy *Acacia baileyana* F. Muell. and *A. longifolia* (Andr.) Willd. through the bush and possibly the spread of a psyllid species *Acizzia uncatoides* (Ferris and Kylver) (Yen 2002). While herbivorous insects are important, the potential adverse effects of invasives may become more readily apparent with pollinators. Pollination of native plant species is another area that could be affected by invasive species. The potential effects of the European Honey Bee have already been discussed. Exotic predators such as the European Wasp may have inhibited pollination of native plants by their native pollinators (Bashford 2001; Hingston *et al.* 2004).

The Bumblebee *Bombus terrestris* Linneaus is another exotic species that has already been introduced into Tasmania, and there is current research on its effects upon the native flora and fauna (Hingston and McQuillan 1998; Hingston 2005, 2006; Hingston *et al.* 2006). An application to introduce the Bumblebee to the mainland for the pollination of glass house plants such as tomatoes was submitted under the Commonwealth *Environment Protection and Biodiversity Conservation Act* (1999), and is still under consideration. In Victoria, the introduction of bumblebees is listed as a potentially threatening process under the *Flora and Fauna Guarantee Act* (1988). This listing cited the potential for *B. terrestris* to (1) pollinate a suite of exotic plants that it pollinates in their countries of origin, resulting in the possible spread of more exotic weeds; (2) compete with native nectar feeding fauna; and (3) cause a possible decline in the seed production of native plant species.

It is difficult to outline uniform guidelines for both exotic and native invasive invertebrate species. Three broad general actions covering both groups may consist of:

1. Exclusion of future invasives (quarantine). This is clear, in principle, for exotic species, but more difficult for native species that are transported across Australia. Native species that become 'pests' can be species (a) that have been moved around with their native host plant; (b) that switch host plant species to colonise new native host plant species; and (c) that have colonised exotic plant species.

For exotic species, effort can be directed at their paths of entry and establishment. The paths of entry considered the most likely points of entry of pests into Victoria are through major seaport and harbour areas, overseas airports and international mail centres (Commonwealth of Australia 2006). International mail centres pose the least risk, firstly because the type of suitable host material (i.e. foliage, timber) is not imported through the centres in the necessary quantities likely to lead to an establishment, and secondly because of the thorough inspection regimes conducted at such locations. International airport arrivals pose a greater risk, as cargo flights have the capacity to bring in sufficient quantities of potential host material such as timber and plant products to allow an exotic establishment to occur. However, by far the greatest threat is posed by the entry of high volumes of cargo through major seaports. In recent times, additional emphasis has been placed on examination of high-risk vectors such as pallet wood and packing crate timber, but despite the high levels of inspection, some movement of exotic pests outside of the port of entry is inevitable.

In addition to initial entry points, it is the experience of overseas countries (including New Zealand and the United States) that it is within a 5 km radius of such entry points that initial establishment of exotic pest species occurs. New Zealand studies have identified that 55% of new forest pest incursions were detected by formal port environs surveys, while 29% were detected during forest surveys (Gadgil 2000). In ports such as Melbourne, Geelong, Westernport and Portland within Victoria, urban areas are interspersed with parks, gardens and street trees, and/or large areas of native bush and planted shelterbelts. These provide potentially attractive lodgement points and subsequent pathways that could allow pest species to establish, reproduce and subsequently spread. Overseas experience has found that if such incursions are not contained and the pests eradicated within two years, subsequent control is virtually impossible.

2. Eradication or control of current invasives. Eradication is generally feasible only at the early stages of colonisation. Once invasives have established, it is generally a matter of minimising spread and numbers through containment strategies.

3. Awareness of future threats. It is important to be aware of the risk of introductions associated with different invasive species. With exotic species, it is easier to determine which species are more likely to enter Australia and to determine their potential range using tools such as climate modelling. Climate change has to be factored into the equation because, with increasing temperatures, the effects on population dynamics of invasive species may be complex as it affects both the invasive species themselves and their natural enemies. The potential effects on native species are more difficult to determine due to our lack of knowledge of most of the native species, and how changes in land use and vegetation patterns across the landscape will affect them.

Another important issue is that society is subject to rapid and sometimes unexpected changes. Some of these changes can accelerate incursion rates and can involve modes and rates of transportation, changes in trading partners and access, and tourism patterns that are difficult to predict. However, recognition of these issues may ensure some allowances are made in the development of future guidelines and predictive models concerning invasive threats to Victoria.

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Challenges in managing miners

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Abstract

Three of the four members of the genus Manorina have been linked to declines in bird diversity and abundance; they are the Noisy Miner *M. melanocephala*, the Bell Miner *M. melanophrys*, and the Yellow-throated Miner *M. flavigula*. The negative influence of these species in remnant vegetation appears to be spreading in eastern Australia. Some habitat restoration and revegetation programs have the potential to exacerbate the problems associated with these species by inadvertently creating additional habitat for them to dominate. Better understanding of the habitat preferences of miners can guide restoration efforts so that they decrease the likelihood of undesirable outcomes. This contribution is based upon an article that appeared in the *State of Australian Birds Report 2006*, as a supplement to *Wingspan* vol 16, no. 4, 2006. (*The Victorian Naturalist*, **124** (2), 2007, 102-105)

Watching a Noisy Miner *Manorina melanocephala* saunter confidently down a Macquarie Street footpath in central Sydney, picking up lunchtime scraps, one gets the distinct impression that this bird 'owns the place'. Regrettably, for much of eastern Australia this has become the case, to the detriment of many other native birds. Noisy Miners belong to the genus *Manorina* (not to be confused with the introduced Common Myna *Acridotheres tristis* from India). Members of this genus of native honeyeater are renowned for living in complex colonies of kin (Dow and Whitmore 1990; Painter *et al.* 2000) which aggressively defend their communal territory from virtually all other species of bird (Dow 1977). While the Noisy Miner is probably the most familiar member of the genus to most Australians, its close relatives the Bell Miner *M. melanophrys* and the Yellow-throated Miner *M. flavigula* have also been implicated in major changes in bird communities and habitats in different parts of the country (Chandler 1922; Loyn *et al.* 1983; Loyn 1987; Clarke and Schedvin 1999; Ewen *et al.* 2003). Ironically, expansion of the range of the Yellow-throated Miner into formally continuous mallee habitats, has contributed to the decline of the fourth member of the genus, the endangered Black-eared Miner *M. melanotis* (Joseph 1986).

The Noisy Miners' communal defence is so effective that they commonly achieve a virtual monopoly on any piece of habitat they choose to colonise (Dow 1977). Unfortunately, their domination of both rural and urban landscapes is increasing. They are what author Tim Low (2002) has labelled one of the native 'winners' from white settlement, and their ascendancy has